



# APD Testing and Cooling Status

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8/20/13



# APD Noise:

## Three promising avenues of investigation with the Caltech Test Stand

- All these from small numbers of APDs tested for ~ 10 hours
- Cooling the APDs to -15C reduces the current excursions seen at Caltech
  - Now seen in 3 sets of “warm, then cold” tests, see next slide
  - 2 more tests could be done.
- Skipping the Organo-Silane coating step at Advanced Coatings appears to eliminate the current excursions seen at Caltech
  - Now seen in 2 sets of tests from one batch of Advanced Coatings processing (the batch had standard Advanced Coatings cleaning, just no Organo-Silane
  - An ounce of prevention is worth a pound of cure?
- Baking coated parts at 80C for 72 hours seems to eliminate the current excursions seen at Caltech
  - Now seen in two separate batches of parts, each with multiple test sections
  - Yet to test parts known to be noisy before baking



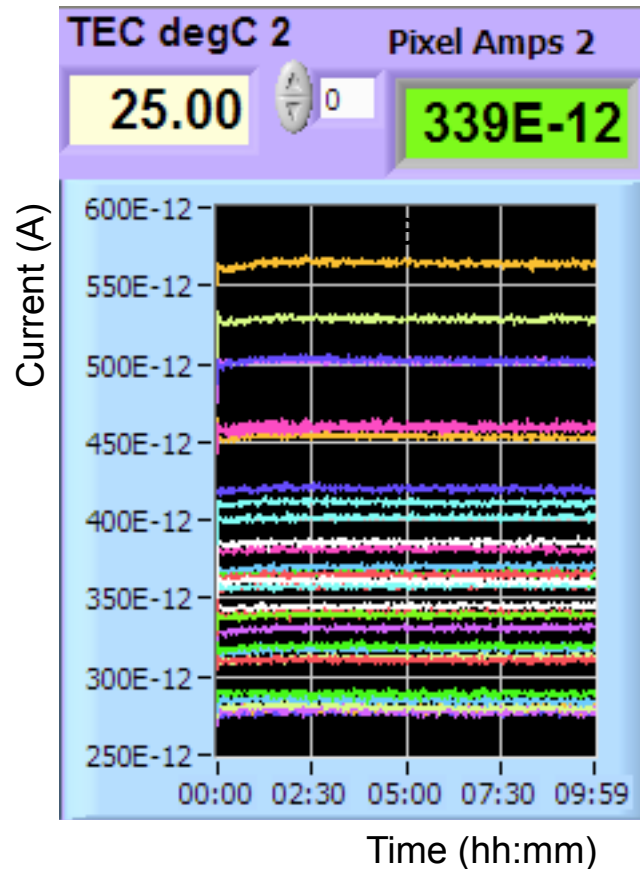
# APD Tests

Tests are multi-hour

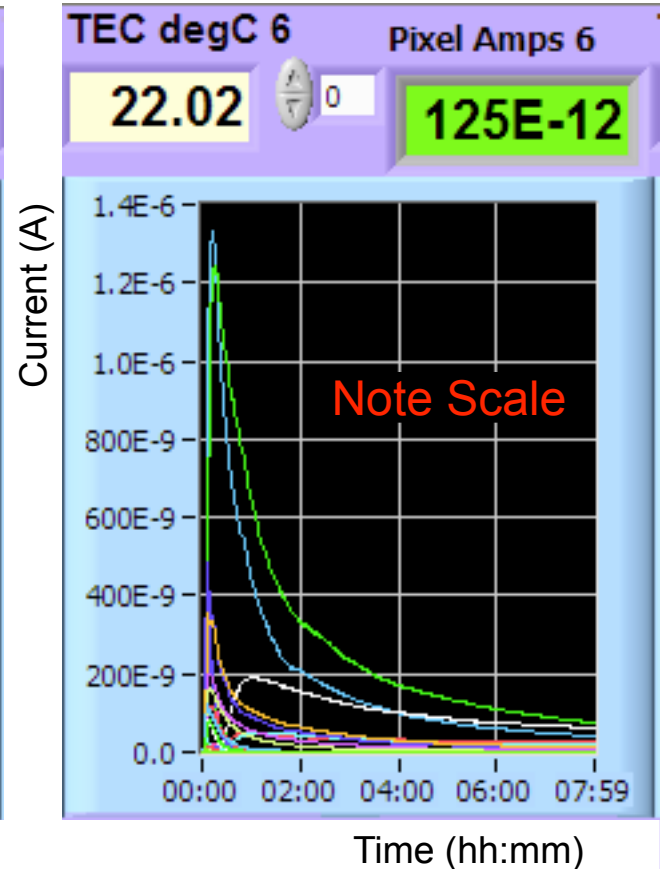
7, 14 APDs tested simultaneously

Bias voltage set by 1st APD to reach gain of 100 (all else lower gain)

Good APD



Current "Excursions"



Dark current spec:  
3 nA/pixel



# Overview of Caltech Warm / Cold tests

Red = WARM room temperature

Blue = COLD -15C

Test #	Date	Test Sample	Result
3	July 8	Coated parts returned from Ash River due to heat sink problems (not noise)	Several with NO current excursions, most <10 nA, many <1 nA
4	July 8	Noisiest Coated parts returned from Ash River	All show current excursions, most > 1 $\mu$ A, two 250 nA
37	Aug 12	Noisiest Coated parts returned from Ash River	One 3.5 nA, one 400 pA, one 50 pA, rest no excursions
2	July 1	Coated parts from Coating Batch #10	Several with large excursions, 100 nA or more.
16	July 15	Coated parts from Coater Batch #10	No excursions seen, but a different kind of spikes, discharges? Thought to be problems with external connectors.
33	Aug 12	Coated parts from Coater Batch #10	No spikes, 5 of 13 parts with small excursions, 1 – 2 nA
7	July 8	Uninstalled parts from early coated batches	All show excursions, several > 1 $\mu$ A, several > 200 nA
14	July 15	Coated parts from Coating Batch #15	Most with small < 10 nA excursions
20	July 22	Coated parts from Coater Batch #15	No excursions > 1 nA
15	July 15	Coated parts from Coating Batch #14	Most with small < 10 nA excursions, some < 1 nA
38	Aug 12	Same parts from Coating Batch #14, BUT these may also have been baked for a week in addition	No excursions, but perhaps tested two things, not one.



# Coating steps at Advanced Coatings

1. Unpack / inspect
2. Clean for 15 minutes in bath  
of 75%  
99.9 isopropyl, 25% de-ionized water
3. Rinse in 99.9 isopropyl
4. Convection bake to remove water and then vacuum store
5. Mask connectors / mounting areas
6. Bake to cure masking
7. Deposit Organo-Silane layer to enhance bonding to Parylene
8. Parylene coat
9. De-mask



# Learned more about Organo-Silane layer

- This is Coater step #7 to enhance bonding between the Parylene and the silicon / pcb / ...
- This is a vapor deposition done in its own chamber used only for Organo-Silane (A174)
  - After A174, the parts are moved to the Parylene deposition chamber where it is pumped down for at least 4 hours before coating
  - If it is the end of the day, it continues to pump until they start the parylene coating the next day
  - Time to Parylene coating is determined by operations only. They know that under vacuum some of the A174 can evaporate. They don't know when it would be gone.
  - There is no target time for the interval between A174 & Parylene and they do not keep track of the time interval.
- The Coater has not tested the deposition
  - “It has been part of processing for 40 years.”
  - “It is supposed to be a thin layer.” “It is conformal.”
  - “It's a long molecule that is supposed to have one end that bonds to inorganics and the other end that bonds to organics, including the Parylene.”
  - In the medical certification of their implantable parts (stents) it was “undetectable”.
- If no A174, Coater pushes using plasma cleaning to promote bonding



# Organo-Silane (A174) tests

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
39	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Tested the first 7 of these	No excursions seen.	Cleaning without A174 appears to prevent excursions in newly cleaned parts	
40	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Tested the second 7 of these	No excursions seen.	Cleaning without A174 appears to prevent excursions in newly cleaned parts	39
41	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Testing of the last 6 of these is ongoing			
42	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Tested the first 7 of these	1 part had an unstable pixel but did not look like an excursion	Cleaning without A174 appears to prevent excursions in newly cleaned parts	
43	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Tested the second 7 of these.	No excursions seen	Cleaning without A174 appears to prevent excursions in newly cleaned parts	42
44	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Testing of the last 6 of these is ongoing			



# Tests of Baking at Caltech

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
28	Aug 5	Tested 14 standard processed parts that had been baked at 80C ( <u>for one week</u> ) after assembly at Caltech.	No excursions seen in two sequential 12 hour runs	Possibly promising, see also Test #34 & 36 of same parts	23, 34, 28
34	Aug 5	<u>Re-tested</u> 14 standard processed parts that had been baked at 80C (1 week) after assembly at Caltech.	No excursions seen	<b>Repeated same result</b>	28
36	Aug 12	Third test of previously baked parts in Test #28	No excursions seen	<b>Repeated same result</b> Still promising	28, 34
45	Aug 12	Test 14 parts from the same standard processed batch a) 7 with <u>72 hour baked parts</u> b) 7 as a control with no baking	a) No current excursions b) ALL parts have excursions > 1 $\mu$ A	<b>Baking seems to work. Unknown if it would “fix” everything.</b>	
46	Aug 12	Test 14 more parts from the same batch as Test #45. a) 7 with <u>72 hour baked parts</u> b) 7 as a control with no baking	a) No current excursions b) ALL parts have excursions > 1 $\mu$ A	<b>Baking seems to work. Unknown if it would “fix” everything.</b>	45



# APD Cooling Status Score Card (8/19/13)

Pre-requisites for APD cooling:

- ✓ Alarms/autodialer notify experts
- ✓ Low level PLC interlock logic shuts off detector (failsafe) E.Voirin
- ✓ FEB firmware shuts off cooling at the TECC N.Felt, et al.
- APD cooling review (schedule for next week?).

Optional pre-requisite

- High level software cooling shutoff at the TECC/HV A.Hatzikoutelis
- ➡ Need list of conditions that shut off TECC/HV G.Lukhanin

Infrastructure needed to set proper APD operating points (warm/cold):

- ✓ APD test data in hardware database L.Mualem
- ✓ MAP of APD locations on the detector D.DeMuth (R.Tesarek)
- ✓ MAP of FEB locations on the detector D.DeMuth (R.Tesarek)
- ✓ FEB test data in hardware database (all but database) R.Schroeter

Can we read FEB ID from the detector for all FEB with APDs?

I would like to run di-block O1\* warm with full gain this week.

**NB: We've never run an APD at its nominal gain (NDOS/FD).**

# Operating Plans for Far Detector

Plans to get to full gain and cold operation:

Item	Goal
✓ Test FEB firmware on NDOS test stand (TEC automatic shutdown)	8/9
✓ Test HV setting on NDOS Test stand (nom. gain)	8/14
✓ Understand FEB firmware/readout threshold calculations	8/16
✓ Run "quiet" APDs cold at full gain on NDSB test stand (> 24 hrs)	8/16
• Run di-block 01* APDs warm overnight at nominal gain -30V (using FEB calibration)	today
• Run di-block 01* APDs ~1 week at full gain (gain = 100) warm	this week?
• Evaluate detector performance from data (full gain, warm)	8/26 - 9/2
• Set di-block 01* APDs to run cold at full gain (~1 day to get cold)	8/26
• Run di-block 01* APDs ~1 week cold at full gain	8/26 - 9/2
• Evaluate detector performance data (full gain, cold)	9/2 - 9/9
• Run "noisy" APDs on NDSB test stand cold at full gain (gain = 100) ~ 1 week	8/19 - 8/26
• Run di-block 02# APDs cold and with full gain ~ 1 week	9/2 - 9/9

**Note:** We still need to evaluate noise on far detector FEB alone, FEB/APD (Tian Xin, ISU)

**Note:** We need to resolve the threshold/ASIC issues else evaluations may prove problematic

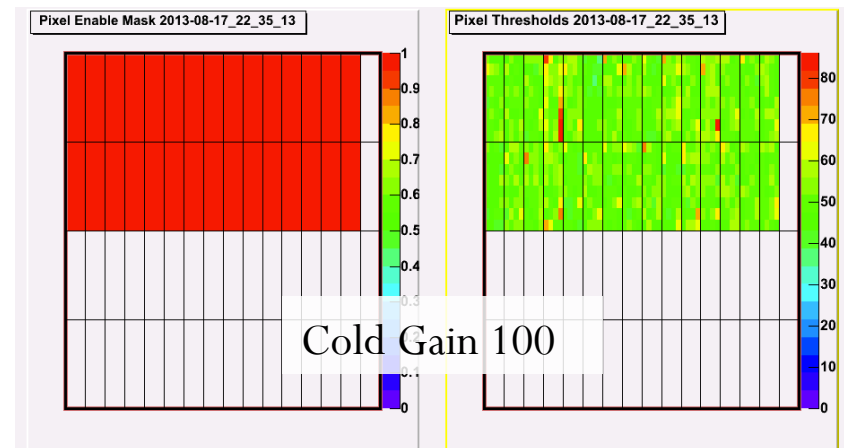
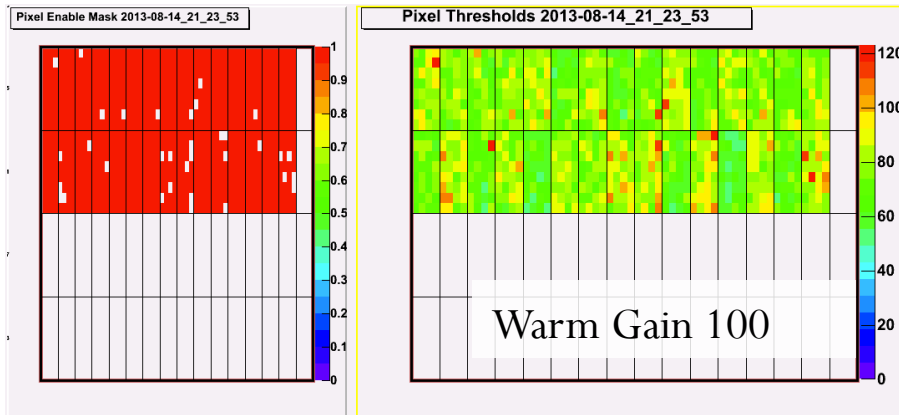
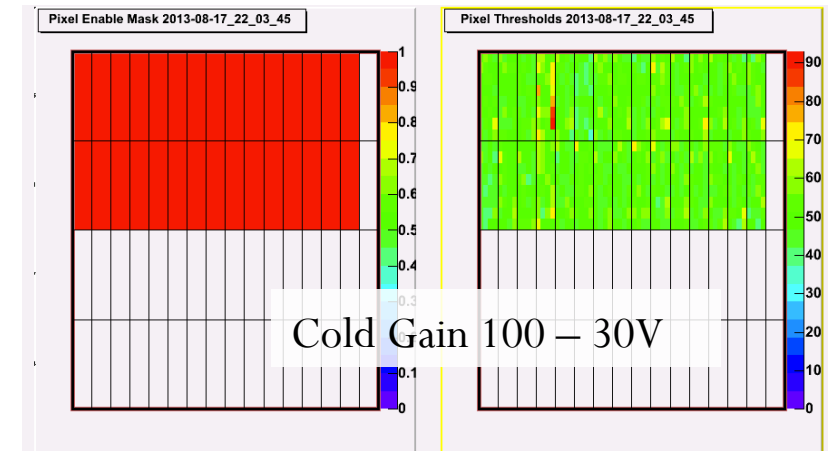
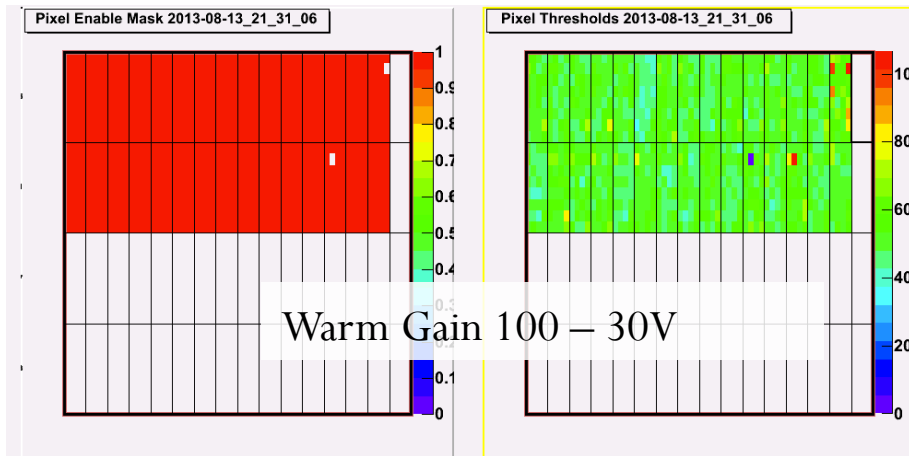
\* indicates the APDs for di-block 01 and DCMs 7,8 on di-block 02 excluding DCMs 3,4 on di-block 01

# indicates the APDs for di-block 02 and DCMs 3,4 on di-block 01 excluding DCMs 6,7 on di-block 02



# Readout Masks/Thresholds

Near Detector Test Stand (30 APDs)





# Summary

Investigation into source of APD noise continues

- Testing without organo-silane looks promising
- Running cold looks promising

Progress toward running at nominal gain/cold continues

- Still on target for running at nominal gain/cold in Sept.





# FULL LIST OF CALTECH TESTS FOLLOWS



# Overview of Caltech APD tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
1	July 1	Developed 10-12 hour test on Caltech test stand. For uncoated parts	Stable dark currents < 1 nA	Parts direct from Hamamatsu look good in this test	
2	July 1	10-12 hour test on Caltech test stand. For coated parts from Coating Batch #10	Several with large excursions, 100 nA or more.	These would not have been seen in earlier QA tests of a few minutes	16
3	July 8	Coated parts returned from Ash River due to heat sink problems (not noise)	Several with NO current excursions, most < 10 nA, many < 1 nA	Current excursions in Caltech test stand match AR experience	1
4	July 8	Noisiest Coated parts returned from Ash River	All show current excursions, most > 1 $\mu$ A, two 250 nA	Current excursions in Caltech test stand match AR experience	3
5	July 8	Uncoated parts retrieved from Advanced Coatings (Coater)	Similar to Hamamatsu delivered uncoated parts, all < 1 nA	Uncoated parts at Coater are still OK	1
6	July 8	Uncoated parts retrieved from Coater, baked at Coater	Similar to Hamamatsu delivered uncoated parts, all < 1 nA	Shelf storage followed by baking at Coater is OK.	1
7	July 8	Uninstalled parts from early coated batches	All show excursions, several > 1 $\mu$ A, several > 200 nA	<b>Focus on Coating process</b>	5,6
8	July 8	Sequential tests, 8 hours, followed by 8 hr on next day	1 <sup>st</sup> test excursions 10s of nA, 2 <sup>nd</sup> test excursions typically ~ 1nA	Possible agreement with Ash River experience in "training"	



# Overview of Caltech APD tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
9	July 8	Test of Parylene coated parts from Fall 2012 held for aging tests of the Parvlene	One excrusion ~ 10 nA, others < 1 nA	<b>Possible to have coating with no excursions in test !</b>	2,3,4,7
10	July 8	Test of <u>Silicone</u> coated parts from Fall 2012 held for aging tests	NO excursions	But recall that <u>silicone</u> did not prevent condensation damage	9
11	July 15	Uncoated parts cleaned at Coater	Several with NO excursions, several with high 100 nA –1 $\mu$ A excursions	Can have differences after cleaning...	
12	July 15	Uncoated parts cleaned <u>and masked</u> at Coater	Several with NO excursions, several with high 100 nA –1 $\mu$ A excursions	Similar to parts <u>cleaned</u> at Coater	11
13	July 15	Uncoated parts cleaned at Caltech in "99.9" Isopropyl <u>bath</u>	6 of 7 with excursions, several with high ~100 nA	Similar to Coater results	12
14	July 15	Coated parts on quick turn-around from Coater, Batch #15	Most with small < 10 nA excursions	<b>Batches have some variation?</b>	
15	July 15	Coated parts from Coater, Batch #14	6 of 7 with small < 10 nA excursions, some < 1 nA	<b>Batches have some variation?</b>	14, 2
16	July 15	Coated parts from Coater Batch #10, <b>cooled to -15C</b>	No excursions seen, but a different kind of spikes, discharges?	<b>Confusing, not seen again, maybe due to external condensation</b>	2



# Overview of Caltech APD tests completed

room temperature unless noted

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
17	July 22	Uncoated parts from Hamamatsu left open to atmosphere at Caltech to simulate possible exposure at	All good except one pixel on one of 14 APDs tested	Repeats test 5 results but at Caltech instead of Coater	5
18	July 22	Uncoated parts cleaned at Caltech a) Rinsed 99.9 Isopropyl, bake at 80C b) Rinsed 99.9 Isopropyl, Nitrogen blow off, bake at 80C	ALL look good, < 1 nA	Limited exposure to isopropyl is OK, no problems induced by any residue	
19	July 22	Coated parts from Coater Batch #13 a) Room temp, b) same at -15C	Room temperature excursions up to 20 nA, NO excursions when cold	Cooling might fix the problem?	
20	July 22	Coated parts from Coater Batch #15 tested at -15C	No excursions > 1 nA	Cooling might fix the problem?	14

- The above tests were the focus of discussions with the visiting Fermilab experts during the week of July 29





# Executive summary from Visiting experts

- The team consisted of Brenna Flaughner (DECAM Project Manager), Paul Rubinov (Engineering Physicist), T.J Sarlina (QA Manager), and Kathy Zappia (QA Specialist).
- **August 8 Team Summary:** Caltech has implemented a program to test the APDs at intermediate steps with the goal of determining where within the cleaning, coating, and assembly procedures the noise is created.
  - Initial tests show APDs directly received by Hamamatsu are good.
  - Tests have ruled out APDs being stored outside of initial packaging in an uncontrolled environment (not cleaned and uncoated) as a cause of noise.
  - Other test results reviewed during the visit imply that the cleaning procedures could be causing or exacerbating the problem, therefore the testing plan implemented by Caltech has shifted towards determining where within the cleaning procedures the problem occurs.
  - The evidence from additional tests at Caltech also suggests that running the devices cold will produce an acceptable dark current however this needs to be verified under operational conditions at Ash River and in the NDOS system due to the differences in the testing stands and operations between Caltech, Ash River, and Fermilab.
- Three recommendations/conclusions
  - Gain experience by cooling the APDs down and run as many as possible for as long as possible.
  - Engage Fermilab to assist in determining the underlying cause of the noise problem.
  - Caltech should continue their systematic search and work with Advanced Coating to determine where in the coating process the problems appear.



# Overview of Caltech APD tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
<b>Caltech continued testing the cleaning procedures:</b>					
21	July 29	Plasma cleaned at Caltech (low pressure, low temp Oxygen plasma). Coater could do this.	"Perfect" on 18 samples		
22	July 29	Retest of plasma cleaned	Current change on 9 of 9 tested	Puzzling, maybe original test of 12 hours was too short?	21
23	July 29	Control = standard cleaning	Current change on 13 of 16 samples	Repeat of earlier results	11,12,13
24	July 29	99.9 Isopropyl <u>rinse</u> (just the 2 <sup>nd</sup> cleaning step at Coater)	Current change on 12 of 18 samples	Contradicts Test #18 Puzzling...	18
25	July 29	Nitrogen dusting	Current change on 9 of 9 samples	Puzzling, apparently changes can occur even with NO	
26	July 29	Tested two sets parts in two separate 16 hour <u>baths</u> of 99.9 Isopropyl.	All parts were perfect.	Contradicts Test #24 since expect that a <u>bath</u> would make	13, 24



# Overview of Caltech APD tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
27	Aug 5	Tested a set of parts that had been de-masked at the Coater. This is the last step on slide 11.	Showed increased current excursions on 12 of 14 APDs.	Intended to test for stresses in de-masking procedure, not at all clear this is	
28	Aug 5	Tested 14 standard processed parts that had been baked at 80C (how long?) after assembly at Caltech.	No excursions seen in two sequential 12 hour runs	??? thinking	23
29	Aug 5	Tests of 2 sets of 7 parts each that were coated after <u>rinse</u> with DI water a) One set with additional 99.9 Isopropl rinse	No excursions were seen in two sequential 12 hour runs.	??? thinking	
30	Aug 5	Re-tested parts blown off with nitrogen in Test #25	Excursions seen, consistent with previous test	<b>Reproduced a result !</b>	25
31	Aug 5	Re-tested plasma cleaned parts from Test #22	Excursions seen, consistent with previous test	<b>Reproduced a result !</b>	22



# Overview of Caltech APD tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
33	Aug 12	Coated parts from Coater Batch #10	No spikes, 5 of 13 parts with small excursions, 1 – 2 nA	Cooling might fix the problem?	2, 16
34	Aug 5	<u>Re-tested</u> 14 standard processed parts that had been baked at 80C (1 week) after assembly at Caltech.	No excursions seen	Repeated same result	28
35	Aug 12	14 APDs from Coater Batch #16 tested	Excess current in 14 of 14 parts: 1 > 1 microA, 5 > 100 nA,	Again, variable results from different batches	
36	Aug 12	Third test of the same parts previously baked for 1 week	Still no excursions	Baking helps	34,28
37	Aug 12	Noisiest Coated parts returned from Ash <b>tested at -15C</b> River	One 3.5 nA, one 400 pA, one 50 pA, rest no excursions		4
38	Aug 12	Same parts from Coating Batch #14 <b>tested at -15C</b> , BUT these may also have been baked for a week in	No excursions, but perhaps tested two things, not one.		15



# Overview of Caltech tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
39	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Tested the first 7 of these	No excursions seen.	Cleaning without A174 appears to prevent excursions in newly cleaned parts	
40	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Tested the second 7 of these	No excursions seen.	Cleaning without A174 appears to prevent excursions in newly cleaned parts	39
41	Aug 12	Have a set of 20 coated parts <u>without A174</u> and with standard cleaning Testing of the last 6 of these is ongoing			
42	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Tested the first 7 of these	1 part had an unstable pixel but did not look like an excursion	Cleaning without A174 appears to prevent excursions in newly cleaned parts	
43	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Tested the second 7 of these.	No excursions seen	Cleaning without A174 appears to prevent excursions in newly cleaned parts	42
44	Aug 12	Have a set of 20 coated parts <u>without A174 but with the addition of plasma cleaning.</u> Testing of the last 6 of these is ongoing			



# Overview of Caltech tests completed

Test #	Week of test	Test Sample	Result	Interpretation	See also test #
45	Aug 12	Test 14 parts from the same batch a) 7 with <u>72 hour</u> baked parts b) 7 as a control with no baking	a) No current excursions b) ALL parts have excursions > 1 $\mu$ A	<b>Baking seems to work. Unknown if it would “fix” everything.</b>	
46	Aug 12	Test 14 parts from the same batch as Test#15. a) 7 with <u>72 hour</u> baked parts b) 7 as a control with no baking	a) No current excursions b) ALL parts have excursions > 1 $\mu$ A	<b>Baking seems to work. Unknown if it would “fix” everything.</b>	